Income Distributional Implications of Water Policy Decisions

Richard E. Just and David Zilberman

Intrasectoral issues have received relatively little attention in analysis of the distributional consequences of natural resource policy decisions. This paper presents a framework for such analysis and examines how intrasectoral issues can change intertemporally, focusing on water policy in agriculture. The results show that income distribution among farmers depends on the stochastic structure of production and marketing, the size distribution of farms, credit market imperfections, and risk aversion in farmer decisions. It is shown that the introduction of water conservation policies may lead to more equitable income distribution among farmers.

Analysis of the distributional implications of natural resource policy decisions presents a multi-dimensional problem. In agriculture three dimensions of these implications are of special concern: intertemporal, intersectoral, and intrasectoral. Methodologies have been well developed for examining intertemporal and intersectoral resource issues [Fisher; Howe; Just *et al.*; Dasgupta and Heal]. Interesting applications of these methodologies to agricultural resource issues are contained in Dixon *et al.*, Regev and Hueth, and Zilberman. However, intrasectoral issues have received relatively little attention in formal economic analysis even though such issues have been a major point of contention in much political controversy. For example, many have argued that the policy of cheap water in California benefitted large corporate farms at the expense of small family farms [Hall and LeVeen].

This paper introduces a framework for explaining the intrasectoral implications of resource policy in an economic sector with characteristics typical of agriculture and examines how intrasectoral issues can change intertemporally. Following the general historical works of Schultz, Cochrane, and Johnson, the framework of the paper recognizes that the major factors characterizing the agricultural sector are competitiveness, uncertainty, risk aversion, imperfect capital markets, technological change (sometimes with fixed costs), and heterogeneity of farm size.

Given the importance of uncertainty in agriculture, analysis of the equity effects of policies for the purposes of policy choice must focus on ex ante rather than ex post distributional implications because, for the most part, policies are determined prior to production decisions. With uncertainty and risk aversion, ex ante income must be discounted for risk. This paper evaluates ex ante income distribution in terms of the distribution of certainty equivalent income among farmers.

The basis for existing inequity among farmers is represented by a joint microparameter distribution of productive resources, financial resources, and risk preferences among farmers. The equity effects of selected resource policies are examined by investigating the distribution of the certainty equivalent of profits induced by the microparameter distribution and then

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considering the changes in this distribution which may be induced over time by various policies. The dimensionality and complexity of this distributional analysis problem are immense. However, several simplifications make the issue tractable for analytical purposes. Farm size, credit availability, and risk preferences are all assumed to be closely related to wealth, so the multi-dimensional microparameter distribution is simplified accordingly. Also, the range of input choices made by the farmer is simplified considerably by focusing only on a few broad choices characterized by fixed-proportions production functions.

The results focus on water policy as an example and show that the distribution of income among farmers can be made either more or less equitable in either an absolute or a relative sense depending on the stochastic structure of production and marketing, the distribution of farm size, and the relative importance of credit market imperfections and risk aversion in farmer decisions. Conditions are developed in which common policies used to conserve water foster distributional equity; other conditions are developed in which they lead to less equity. It should be emphasized, however, that this paper is concerned only with distribution within the agricultural sector and does not concern itself with distributional issues between producers and consumers (which are investigated at length in other literature). Finally, the probable long-term effects of these policies on the farm size distribution and the cost of future resource conservation are considered.

The basic microeconomic foundation of the framework is developed in section 2, and the microeconomic behavior of farmers with various characteristics is investigated in section 3. The effects of alternative policies are examined in section 4. Short-term equity effects are characterized in section 5. The implications for long-term equity and resource conservation are discussed in section 6, and section 7 contains the conclusions.

The Micromodel

The microeconomic model of this paper follows Just and Zilberman [1983] and is outlined as follows. Consider initially a single farm with fixed landholdings, L, valued at price p_L. Suppose the farm can allocate its land in any proportion between two Leontief technologies (each of which may itself represent various cropping mixtures). Let net returns per acre under technology i be represented by π_i, i = 1, 2, with joint distribution.

$$\begin{bmatrix}\pi_1\\ \pi_2\end{bmatrix} \sim N\left[\begin{pmatrix}m_1\\ m_2\end{pmatrix}, \begin{pmatrix}\sigma_1^2 & \rho\sigma_1\sigma_2\\ \rho\sigma_1\sigma_2 & \sigma_2^2\end{pmatrix}\right]$$

where $m_1 > 0$, $m_2 > 0$, and $0 < \rho < 1$.

The two technologies are assumed to differ in their degree of use of water. For example, in problems of irrigation versus nonirrigation, such as in the Western Great Plains, technology 1 may be nonirrigation while technology 2 is irrigation. In problems of selection of irrigation technology, such as in California, technology 1 may be irrigation by flooding while technology 2 is irrigation by sprinkler or drip.

To accommodate these cases, assume that technology 2 requires an additional cost of w per acre (possibly negative) over technology 1 which translates into an opportunity cost of $w(1 + r)$ where r is the (opportunity) cost of funds. Also, to consider fixed costs of irrigation adoption, suppose a fixed investment cost, k, must be incurred with annualized cost rk before any land can be allocated to technology 2. This cost may involve both capital costs and learning costs. Thus, the investment decision is a discrete choice, whereas the land allocation decision is a continuous choice. Both of these costs must be considered in the context of available credit, K, in making the investment decision. The credit constraint is

$$I(k + wL_2) \leq K$$

where $I = 0$ if the fixed cost is not incurred, $I = 1$ if the fixed cost is incurred, and L_2 is the amount of land allocated to the second technology. We assume that the credit constraint is not binding if the fixed cost is not incurred.

Now assume that the farmer is risk averse with utility function $U(\cdot)$ defined on wealth, $U' > 0$, $U'' \leq 0$. Suppose that wealth, W, at the end of each season is represented by the sum of the land value, $P_L L$, and the net return from production. Where L_1 is the amount of land allocated to technology 1, the decision problem is

$$\max_{\substack{I=0,1 \\ I_1, I_2}} EU[p_L L + \pi_1 L_1 + I(\pi_2 L_2 - rk)] \quad (1)$$

subject to

$$L_1 + L_2 \leq L$$
$$I(k + wL_2) \leq K$$
$$L_1, L_2 \geq 0.$$

The results assume that risk aversion is not so great or returns are not so poor as to prevent use of all available land. Thus, the land constraint can be replaced by a strict equality.

To solve this decision problem, consider first the choice of land allocation given the investment decision. Assuming full utilization, the optimal decision with $I = 0$ is $L_1 = L$. Thus, expected utility is

$$V_1(L) = EU[(p_L + \pi_1)L]. \quad (2)$$

Alternatively, given the investment is undertaken and assuming full land utilization, the objective of the decision problem in (1) becomes

$$\max_{L \geq L_2 \geq 0} EU[(p_L + \pi_1)L + (\pi_2 - \pi_1)L_2 - rk] \quad (3)$$

subject to

$$k + wL_2 \leq K.$$

In another context, Just and Zilberman (1984) show that the solution to (3) subject to the constraints is approximated by

$$L_2 = \max\{0, \min [L_2^c, L_2^r, L]\} \quad (4)$$

where $L_1 \equiv L - L_2$ and

$$L_2^r = \frac{e}{\phi v} + LR, \quad L_2^c = \frac{K - k}{w} \quad (5)$$

$$R = \frac{\sigma_1^2 - \rho\sigma_1\sigma_2}{v}, \quad \phi = -\frac{U''(\bar{W})}{U'(\bar{W})} \quad (6)$$

$$e = E(\pi_2 - \pi_1), \quad v = Var(\pi_2 - \pi_1) \quad (7)$$

$$\bar{W} = p_L L + m_1 L + eL_2 - rk \quad (8)$$

and ϕ is the coefficient of absolute risk aversion at expected wealth. Note that L_2^r is the solution to the expected utility maximization problem when L_2 is unconstrained, and L_2^c denotes land allocated to the second technology when the credit constraint is binding.

To determine the investment decision, let

$$V_2(L, L_2) = EU[p_L L + \pi_1(L - L_2) + \pi_2 L_2 - rk]. \quad (9)$$

Assuming that the farmer is either myopic or considers future periods to be like the current one, the farmer does not undertake the investment if $V_1 > V_2$ and does undertake the investment if $V_2 > V_1$.

Alternative Farm Behavioral Regimes

The decision rules derived above suggest that the farmers can be classified into four regimes of behavior according to their technology and land allocation choices. The first is the specialized noninvestors' regime, and it includes farmers for whom $V_1 > V_2$ and $L_2 = 0$; the second regime is of credit-constrained investors, and it includes farmers with $I = 1$ and $L_2 = L_2^c$; the third is the specialized investors' regime, and it includes the farms with $I = 1$ and $L_2 = L$; and the fourth is the risk-diversifying investors' regime, and it consists of farms with $I = 1$ and $L_2 = L_2^r$.

To examine policy issues quantitatively in the context of the model, a distribution of microparameters among farmers must be specified. The results here focus on the distribution of risk preferences, farm size, and credit availability with farmers assumed to be identical in other respects.

This is done by considering a distribution of farm size f(L) and then specifying a relationship between farm size and risk preferences and credit.

Given this distribution of farm size, risk preferences, as reflected by the coefficient of absolute risk aversion, are assumed to be related to initial wealth or farm size following the equation

$$\phi = \tilde{\phi}(W_0) = \phi(L)$$

where initial wealth is $W_0 = p_L L$. For notational purposes, let the elasticity of risk aversion be represented by

$$\eta = \eta(L) = \frac{\partial\phi}{-\partial L}\frac{L}{\phi}$$

and assume $0 < \eta < 1$. Absolute risk aversion is assumed to be constant for each individual farmer; however, $\eta > 0$ implies that larger farmers have less absolute risk aversion, and $\eta < 1$ implies that larger farmers have more relative risk aversion following Arrow's arguments. For simplicity, the availability of credit is also assumed to be related to initial wealth or, equivalently, to farm size following the equation $K = aL$. This relationship is consistent with many general credit-granting practices. Finally, note that following the assumption of constant absolute risk aversion for **individual** farmers, the certainty equivalent of income corresponding to (2) and (9) is

$$V_1(L) = (p_L + m_1)L - \frac{\phi}{2}\sigma_1^2 L^2 \tag{10}$$

$$V_2(L, L_2) = (p_L + m_1)L + (m_2 - m_1)L_2 - rk - \frac{\phi}{2}(\sigma_1^2 L_1^2 + \sigma_2^2 L_2^2 + 2\rho\sigma_1\sigma_2 L_1 L_2). \tag{11}$$

Note that the certainty equivalents in (10) and (11) are measured in money terms so that changes in the distribution of certainty equivalent are equivalent to changes in the distribution of welfare effects (compensating or equivalent variation) of policy changes [Just *et al.*]. The certainty equivalent of individual farms with farm size L thus follows

$$V(L) = \begin{cases} V_1(L) = (p_L + m_1)L - \dfrac{\phi}{2}\sigma_1^2 L^2 \\ \quad \text{for specialized noninvestors} \\ V_2(L, L_2^c) = \left[p_L + m_1 + \dfrac{ea}{w}\right]L \\ \qquad - \dfrac{e}{w} + rk \\ \qquad - \dfrac{\phi}{2}[\sigma_1^2(L - L_2^c)^2 \\ \qquad + \sigma_2^2(L_2^c)^2 \\ \qquad + 2\rho\sigma_1\sigma_2 L_2^c(L - L_2^c)] \\ \quad \text{for credit-constrained investors} \\ V_2(L, L) = -rk + (p_L + m_2)L \\ \qquad - \dfrac{\phi}{2}\sigma_2^2 L^2 \\ \quad \text{for specialized investors} \\ V_2(L, L_2^r) = -rk + (p_L + m_1 + Re)L \\ \qquad + \dfrac{e^2}{2\phi v} - \dfrac{\phi}{2} \\ \qquad \cdot(\sigma_1^2 - R^2 v)L^2 \\ \quad \text{for risk-diversifying investors} \end{cases} \tag{12}$$

To relate farm size to the certainty equivalent, it remains to see how the four behavioral regimes are related to farm size. Using the model of section II, the relationship of acreage allocation to farm size can be determined as illustrated in Figure 1 following (4). Note that acreage allocation (to technology 2) is physically constrained to lie on or between lines $L_2 = L$ (the 45-degree line) and $L_2 = 0$. Second, the acreage allocation is constrained to lie on or below the credit limitation, $L_2 = L_2^c$. When these limitations are not binding, the acreage allocation follows the risk-diversification line, $L_2 = L_2^r$, if fixed costs are zero. Finally, when fixed costs are positive, there are certain farm sizes for which fixed costs cannot be adequately spread given the risk and available credit; therefore, the investment is not worthwhile.

As shown in Figure 1, farm sizes can be segmented to four groups, each corresponding to a behavioral regime. Farms smaller than L_a are specialized noninvestors, farms of sizes between L_a and L_b are credit-constrained investors, specialized investors belong to the segment (L_b, L_c), and risk-diversifying investors have sizes greater than L_c.

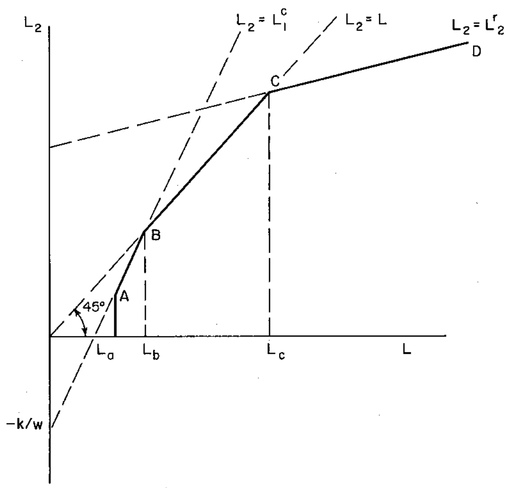

Figure 1. Use of a Technology as a Function of Farm Size.

Note that some of these regimes may vanish and the ordering of regimes is different under different conditions.[1] To determine which cases can occur under alternative sets of conditions, note first that

$$\frac{dL_2^r}{dL} = \eta\frac{L_2}{L} + (1 - \eta)R$$
$$\geqq 1 \text{ as } \eta(m_2 - m_1)$$
$$\gtreqless \phi\sigma_2 L(\sigma_2 - \rho\sigma_1) \qquad (13)$$

while

$$\frac{dL_2^c}{dL} = \frac{a}{w} \gtreqless 1 \quad \text{as} \quad a \gtreqless w. \qquad (14)$$

To understand these conditions further, note from (5) that $0 < L_2^r < L$ implies

$$\phi\sigma_1 L(\sigma_2 - \sigma_1) < m_2 - m_1 < \phi\sigma_2 L(\sigma_2 - \rho\sigma_1). \qquad (15)$$

Comparing (13) and (15) reveals that $dL_2^r/dL < 1$ if $m_2 > m_1$. Next, note that $\sigma_2 > \sigma_1$ implies that the right-hand side of the condition in (13) is positive; thus, either $m_2 > m_1$, in which case $dL_2^r/dL < 1$ from above, or $m_2 \leq m_1$, in which case (13) also implies $dL_2^r/dL < 1$. Thus, $dL_2^r/dL > 1$ can occur only if $m_2 < m_1$ and $\sigma_2 < \sigma_1$. From (13), a specific condition that causes $dL_2^r/dL > 1$ is $\eta = 0$ and $\rho > \sigma_2/\sigma_1$. By analogy (since $dL_1^r/dL = 1 - dL_2^r/dL$), $dL_2^r/dL > 0$ if $\sigma_1 > \sigma_2$ or $m_1 > m_2$ while $dL_2^r/dL < 0$ if $\eta = 0$ and $\rho > \sigma_1/\sigma_2$.

These possibilities give rise to the eight cases listed in Table 1, each of which causes a distinct ordering of behavioral regimes by farm size as indicated. The specific conditions in Table 1 are sufficient to give rise to each case although not necessary; that is, they do not exhaust the parameter space. Also, note that one or more regimes may vanish under some further special conditions which may effectively equate some cases. For example, if fixed costs are zero when a > w, credit can never be constraining—so, cases 1 and 2 produce the same effective ordering of observable behavioral regimes.

For purposes of discussion, the resulting eight cases can be described intuitively by the following:

- Case 1. Near constant absolute risk aversion among farms. Very high correlation of profits among technologies or very low-risk investment technology. High credit.
- Case 2. Near constant absolute risk aversion among farms. High correlation of profits among technologies or low-risk investment technology. Low credit.
- Case 3. High-profit investment technology or high-risk technology (not both). Very low credit.
- Case 4. Near constant absolute risk aversion among farms. High correlation of profits among technologies or low-risk investment technology. Very high credit.
- Case 5. High-profit investment technology or high-risk investment technology (not both). High credit.

[1] Here irrigation is assumed to be a risk-neutral input. Arguments can be made supporting both risk-increasing and risk-reducing effects. The results of this paper hold, however, as long as any risk effects of irrigation are secondary to the effects on mean returns. This is likely the case.

Table 1. Behavioral Regimes by Farm Size.[a]

Case	Figure 1 Relationships	Sufficient Specific Conditions	Ordering of Behavioral Regimes by Farm Size (Small to Large)
1	$\frac{dL_2^r}{dL} > \frac{dL_2^c}{dL} > 1$	$m_1 > m_2, \sigma_2 < \sigma_1$ $\eta = 0, \rho \gg \rho_2, a > w$	Specialized noninvestors, risk diversifiers, credit constrained, specialized investors
2	$\frac{dL_2^r}{dL} > 1 > \frac{dL_2^c}{dL}$	$m_1 > m_2, \sigma_2 < \sigma_1$ $\eta = 0, \rho > \rho_2, a < w$	Specialized noninvestors, risk diversifiers, specialized investors, credit constrained
3	$1 > \frac{dL_2^r}{dL} > \frac{dL_2^c}{dL}$	$m_2 > m_1$ or $\sigma_2 > \sigma_1$ (but not both), $a \ll w$	Specialized noninvestors, specialized investors, credit constrained
4	$\frac{dL_2^c}{dL} > \frac{dL_2^r}{dL} > 1$	$m_1 > m_2, \sigma_1 > \sigma_2$ $\eta = 0, \rho > \rho_2, a \gg w$	Specialized noninvestors, credit constrained, risk diversifiers, specialized investors
5	$\frac{dL_2^c}{dL} > 1 > \frac{dL_2^r}{dL} > 0$	$m_2 > m_1$ or $\sigma_2 > \sigma_1$ (but not both), $a > w$	Specialized noninvestors, credit constrained, specialized investors, risk diversifiers
6	$\frac{dL_2^c}{dL} > 1 > 0 > \frac{dL_2^r}{dL}$	$\eta = 0, \rho > \rho_1, a > w$	Specialized noninvestors, credit constrained, specialized investors, risk diversifiers, specialized noninvestors
7	$1 > \frac{dL_2^c}{dL} > \frac{dL_2^r}{dL} > 0$	$(m_2 \gg m_1, \sigma_2 < \sigma_1)$ or $(m_2 < m_1, \sigma_2 \gg \sigma_1), a < w$	Specialized noninvestors, specialized investors, credit constrained, risk diversifiers
8	$1 > \frac{dL_2^c}{dL} > 0 > \frac{dL_2^r}{dL}$	$\eta = 0, \rho > \rho_1, a < w$	Specialized noninvestors, specialized investors, credit constrained, risk diversifiers, specialized noninvestors

[a] Note that $\rho_1 = \sigma_1/\sigma_2$ and $\rho_2 = \sigma_2/\sigma_1$.

TABLE 2. The Marginal Effect of Policies on Farmers' Welfare.

Policy Parameter, (y)	Specialized Noninvestors, $V_1(L)$	Credit-constrained Investors, $V_2(L, L_2^c)$	Specialized Investors, $V_2(L, L)$	Risk-diversifying Investors, $V_2(L, L_2^r)$
		$\partial V / \partial y$		
m_2	0	$L_2^c > 0$	$L > 0$	$L_2^r > 0$
m_1	$L > 0$	$L_1^c > 0$	0	$L_1^r > 0$

Case 6. Absolute risk aversion does not vary among farms. High correlation of profits among technologies or high-risk investment technology. High credit.

Case 7. Very high-profit, low-risk investment technology or very high-risk, low-profit investment technology. Low credit.

Case 8. Near constant absolute risk aversion among farms. High correlation of profits among technolgoies or high-risk investment technology. Low credit.

Modeling Effects of Water Resource Policies

Based on the model of section 3, this section investigates the effects on farmer behavior of several alternative water resource policies. The parameters through which these policies are reflected in the model are m_1 and m_2.

Policy Question 1. The effect of water pricing on irrigation/nonirrigation decisions. This question is intended to consider farmer behavior in regions, such as the Western Great Plains, where the important effects have to do with decisions of installing and using center-pivot irrigation technology. For this case, suppose that technology 1 represents production by traditional dryland methods while technology 2 represents production using center-pivot irrigation equipment. The fixed cost that facilitates technology 2 is the cost of drilling wells and installing center-pivot irrigation equipment. The obvious effect of, say, raising the price of water by policy legislation in the model is to reduce m_2, the net returns per acre from irrigation farming.

Policy Question 2. The effect of water pricing on adoption of water-saving technologies. This question is intended to consider farmer behavior in regions of the southwest where all crops are irrigated but farmers can switch from conventional gravity methods to sprinkler or drip irrigation. For this case, let technology 1 represent the conventional method while technology 2 represents a water-saving technology. The fixed cost of facilitating the water-saving technology consists mainly of learning costs and investment in pressure pumps and pipes or tubes to increase water pressure. The effect of raising water price is, thus, to lower both m_1 and m_2; but m_1 is lowered more than m_2 because it uses water more intensely.

Table 3. The Marginal Effects of Policies on Absolute Income Distribution Within Regimes.

Policy Parameter (y)	Specialized Noninvestors $V_1(L)$	Credit-constrained Investors $V_2(L_1L_2^c)$	Specialized Investors $V_2(L_1L)$	Risk-diversifying Investors $V_2(L_1L_2^r)$
		$\partial^2 V/\partial L\, \partial y$		
m_2	0	$\frac{a}{w} > 0$	1	$\frac{dL_2^r}{dL} \begin{cases} > 0 \text{ if } m_2 < m_1 \text{ or } \sigma_1 > \sigma_2 \\ < 0 \text{ if } m_2 > m_1;\ \eta = 0;\ \rho > \rho_1 \end{cases}$
m_1	1	$1 - \frac{a}{w} \begin{cases} > 0 \text{ if } a < w \\ > 0 \text{ if } a > w \end{cases}$	0	$1 - \frac{dL_2^r}{dL} \begin{cases} > 0 \text{ if } m_2 > m_1 \text{ or } \sigma_2 > \sigma_1 \\ < 0 \text{ if } m_2 < m_1;\ \eta = 0;\ \rho > \rho_2 \end{cases}$

Table 4. The Marginal Effects of Policies on Relative Income Distribution Within Regimes.

Policy Parameter (y)	Specialized Noninvestors $V_1(L)$	Credit-constrained Investors $V_2(L_1L_2^c)$	Specialized Investors $V_2(L_1L)$	Risk-diversifying Investors $V_2(L_1L_2^r)$
		$\partial^2(V/L)/\partial L\ \partial y$		
m_2	0	$\frac{k}{wL^2} > 0$	0	$\frac{(\eta - 1)e}{\phi vL^2}\begin{cases} > 0 \text{ if } m_2 < m_1 \\ < 0 \text{ if } m_2 > m_1 \end{cases}$
m_1	0	$-\frac{k}{wL^2} < 0$	0	$\frac{(1 - \eta)e}{\phi vL^2}\begin{cases} > 0 \text{ if } m_2 > m_1 \\ < 0 \text{ if } m_2 < m_1 \end{cases}$

With this characterization, both of the above policies can be represented in terms of effects on m_1 and m_2^1. Table 2 derives the marginal effects of each of these parameters on the expected utilities of farmers in each behavioral regime using equation (12) where $y = m_1$ or m_2. Note that some of these results are derived by duality.

Intrasectoral Equity Effects of Water Resource Policies

To investigate analytically the equity effects of water policies, several concepts of qualitative change in income distribution are convenient. This paper uses four qualitative concepts of distributional effects: a spread in absolute income distribution, a contraction in absolute income distribution, a spread in relative income distribution, and a contraction in relative income distribution.

A policy is said to spread the absolute income distribution of farmers if, for every pair of farmers, the difference in their certainty equivalent is no smaller after the change than before and the difference is larger for at least one pair. A policy is said to contract absolute income distribution if, for every pair of farmers, the difference in certainty equivalent is no larger and is smaller for at least one pair. To see whether policy effects are larger or smaller for more well-off individuals, Table 3 derives $\partial^2\bar{V}/(\partial L\partial y)$ where y represents some policy instrument. Absolute income distribution spreads (contracts) if $\partial^2\bar{V}/(\partial L\partial y) > (<) 0$ over all farm sizes.

To consider equity effects of policies on relative income distribution, certainty equivalent is deflated by farm size. Farm size is a common measure of scale of operation. Most policies can be expected to have a larger absolute impact on income of larger farms. However, if the increases in income on larger farms are larger even relative to scale of operation, a rather severe spread in income distribution results. Such effects are of acute political concern [Tweeten] as they suggest that the associated policies "help the rich get richer." Thus, to examine further the equity effects of policies, the benchmark of farm size is introduced to determine the degree to which income distribution is spread. A policy is said to spread (contract) the relative income distribution if, for every pair of farmers, the difference in their ratio of certainty equivalent to farm size is no smaller (larger) after the change than before and the difference is larger (smaller) for at least one pair. To see how changes in policy affect the distribution of $\bar{V}/L$, first note that

$$\frac{\partial(\bar{V}/L)}{\partial y} = \frac{\partial\bar{V}}{\partial y}\frac{1}{L} \tag{16}$$

which can be obtained by dividing the entries of Table 2 by L. The slope of (16) with respect to farm size is derived in Table 4 using the identity

$$\frac{\partial^2(\bar{V}/L)}{\partial L\partial y} = \frac{\partial^2\bar{V}}{\partial L\ \partial y}\frac{1}{L} - \frac{\partial\bar{V}}{\partial y}\frac{1}{L^2}.$$

Relative income distribution spreads (contracts) if this derivative is positive (negative) over all farm sizes.

To demonstrate the implications of the results in Tables 3 and 4, consider the equity effects of a policy that increases water price on farms in an area that is switching to irrigation technology (the effects of reducing m_2). Following the first row of Table 3, absolute income distribution is unaffected among noninvestors because they do not buy water. Absolute income distribution contracts among credit-constrained investors because larger farms, which have more credit, use more irrigation technology and buy more water. Income distribution contracts among specialized investors because larger farms that use all of their land with irrigation buy more water. Among risk-diversifying investors, absolute income distribution contracts if the irrigation technology is less risky than the nonirrigation technology ($\sigma_1 > \sigma_2$). However, it spreads if absolute risk aversion is constant among farms ($\eta = 0$), the correlation of profits between irrigation and nonirrigation technologies is high ($\rho > \rho_1$), and the irrigation technology is riskier than the nonirrigation technology ($\sigma_2 > \sigma_1$, which is necessary for $\rho > \rho_1$) assuming the irrigation technology produces more short-run expected profits per acre ($m_2 > m_1$). The conditions that cause absolute income distribution to contract (spread) among risk-diversifying investors are the same as those that cause land allocated to irrigation to increase (decrease) with farm size. Constant absolute risk aversion causes absolutely less land to be allocated to irrigation on larger farms if irrigation is more risky and the correlation is too high to allow effective diversification because larger farms have more absolute risk and, thus, must give up more at the margin to avoid risk.

Next consider the effects on relative income distribution within each behavioral regime of a water price increase in a region that is partially irrigated. Following the first row of Table 4, relative income distribution is unaffected among noninvestors again because they do not purchase water. Relative income distribution contracts among credit-constrained investors if the fixed cost is positive since larger farms can better spread fixed costs. Relative income distribution is unaffected among specialized investors because total water use is proportional to farm size. Whether relative income distribution spreads or contracts among risk-diversifying investors depends on whether land allocated to irrigation increases or decreases relative to farm size. If the irrigation technology produces more (less) expected short-run profits per acre, relative income distribution spreads (contracts) among risk-diversifying farms.

Following this approach, one can find the qualitative effects of each policy of this paper on the short-run distribution of income with behavioral regimes. Having determined these qualitative effects, it remains to investigate the effects on the entire income distribution. To do this, one must consider how farms are distributed among behavioral regimes. This is done in Table 5 for each policy question in a variety of special cases. To understand how Table 5 is derived, note that any farmer at the margin between two behavioral regimes would have the same certainty equivalent wealth in either regime. Thus, income distribution over two or more behavioral regimes that are consecutively ordered following Table 1 will spread (contract) if the same is so for every individual behavioral regime. On the other hand, if there is any intervening behavioral regime affected in the opposite qualitative Table 5 direction, the overall effect is ambiguous (even though no farms fall within the behavioral regime) unless no farm size (even hypothetical) falls within the regime.

For example, following the results above for the case of raising water price in a partially irrigated region, absolute income distribution contracts if the irrigation technology is less risky (Table 5, row 1b) while both the absolute and relative income distributions contract if irrigation yields less short-run expected profit per acre (Table 5, Case 1d) since the same qualitative effect occurs in every behavioral regime. The latter case is not plausible unless farmers have overinvested in irrigation, say, owing to poor price expectations; but the former case is quite plausible.

On the other hand, if credit is sufficiently abundant so that no farm size leads to credit-constrained investment, relative income distribution spreads if irrigation produces more short-run expected profit per acre (Table 5, row 1f). Furthermore, both the relative and absolute income distributions spread if irrigation leads to more short-run expected profits and more risk, absolute risk aversion is constant over farms, correlation of profits between technologies is high, and either risk and risk aversion are so high that credit would not be limiting and no farm would specialize in irrigation for any farm size or (since these conditions imply either Case 6 or 8 of Table 1), no existing farm size is as small as or smaller than farm sizes that fall into the specialized or credit-constrained investor regimes (Table 5, row 1e). In spite of the many qualifications of this result, it seems quite plausible. Finally, if risk or risk aversion is low enough so that risk diversification does not play a role or if conditions for Case 5 or 7 in Table 1 hold and no farms are large enough to fall into the risk-diversification regime, absolute income distribution contracts if at least some farms are investors (Table 5, row 1a) and relative income distribution also contracts if at least some farms are investors constrained by credit (Table 5, row 1c).

Following this approach, the results for cases too numerous to discuss here are apparent.[2] Because of the complexity of these many cases, the remainder of this paper considers only a few of the results that seem most likely in the absence of empirical evidence tailored to the necessary distinction of cases in Tables 1 and 5. For this purpose, assume under Policy Question 1 that irrigation leads to higher short-run expected profits per acre than does nonirrigation because of the need to recover fixed costs. Assume, also, that very small farms cannot find sufficient credit to invest because of inability to spread fixed costs but that credit becomes sufficient to allow specialized investment at some farm size; thus, $m_2 > m_1$ and $a > w$. These assumptions suggest that farms are distributed among behavioral regimes according to Case 5 of Table 1. From Table 5, therefore, the effect of raising water price is to contract both the absolute and relative income distributions among all farms below a certain size where the risks of specialization are so large that complete irrigation is not undertaken even if credit is sufficient (Table 1, Cases 1a and 1b). If irrigation offers sufficiently low risk relative to nonirrigation, there may be no farms larger than this critical size. Otherwise, relative income distribution spreads among these larger farms while the effect on absolute income distribution is unclear (Table 1, Case 1f). Thus, in the former case, conserving water by increasing water price has not only the usual desired intersectoral efficiency effect but, also, a desirable equity effect among agricultural producers. In the latter case, however, the equity effect is seemingly undesirable—contracting the income distribution among small producers while spreading it among large producers.

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[2] Some simple facts that should be borne in mind in interpreting Tables 1 and 5 are as follows: $\rho > \rho_1$ implies $\sigma_1 < \sigma_2$; $\rho > \rho_2$ implies $\sigma_2 > \sigma_1$; $\sigma_1 < \sigma_2$ implies $\rho < \rho_2$; $\sigma_2 < \sigma_1$ implies $\rho < \rho_1$; m_2; $> m_1$ and $dL_2^r/dL > 1$ imply no farms can be risk diversifiers; $m_2 < m_1$ and $dL_2^r/dL < 0$ imply no investment; $k = 0$ and $a < w$ imply no farms can be constrained by credit.

TABLE 5. The Marginal Effects of Resource Policies on Income Distribution.

Policy Question/ Case		Specialized Noninvestors	Credit Constrained Investors	Specialized Investors	Risk Diversifying Investors	Special Conditions	Income Distribution[a] Absolute	Income Distribution[a] Relative
1 ($m_2\downarrow$):	a	X	X[b]	X[b]			C	
	b	X	X[b]	X[b]	X[b]	$m_2 < m_1$ or $\sigma_1 > \sigma_2$	C	
	c	X	X[b]	X			C	C
	d	X	X[b]	X	X[b]	$m_2 < m_1$	C	C
	e	X			X[b]	$m_2 > m_1$, $\eta = 0$, $\rho > \rho_1$	S	S
	f	X		X	X[b]	$m_2 > m_1$		S
2 ($m_1\downarrow\downarrow$, $m_2\downarrow$):	a	X		X			C	
	b	X	X	X		$a < w$	C	
	c	X		X	X	$m_2 > m_1$ or $\sigma_2 > \sigma_1$	C	
	d	X	X	X	X	$a < w$, $m_2 > m_1$ or $a < w$, $\sigma_2 > \sigma_1$	C	
	e	X		X	X[b]	$m_2 > m_1$	C	C
	f		X			$a \gg w$	S	S
	g				X	$m_1 \gg m_2$, $\eta = 0$, $\rho \gg \rho_2$	S	S
	h		X		X	$a \gg w$, $m_1 \gg m_2$, $\eta = 0$, $\rho \gg \rho_2$	S	S
	i	X	X[b]	X				S
	j	X	X[b]	X	X[b]	$m_2 < m_1$		S

[a] C = contracts and S = spreads.
[b] At least one farm must be in one of these regimes.

Considering the case of Policy Question 2, the assumptions for Policy Question 1 again seem to be appropriate; that is, conversion from flood irrigation to sprinkler or drip involves fixed costs of learning as well as investments in pressure pumps and pipes or tubes. Because of this fixed cost, it seems reasonable that small farms could not find sufficient credit while observed behavior suggests that some (larger) farms find sufficient credit for specialized investment. Thus, again, $m_2 > m_1$ and $a > w$. These assumptions imply that farms are distributed among behavioral regimes according to Case 5 of Table 1. Using this information in Table 5 implies (by Cases 2c and 2d) that raising water price contracts both the absolute and relative income distributions if credit is sufficiently abundant so that no farm size sufficient to spread fixed costs would find credit constraining (this assures that the noninvesting, specialized investing, and risk-diversifying regimes cover all farm sizes). On the other hand, if some investing farms are limited by credit, the relative income distribution spreads among those farms (Table 5, Case 2i) while both the absolute and relative distributions spread if credit is high, $a \gg w$, but still constraining (Case 2h). In this case, the overall absolute income distribution will spread if risk is too low to cause diversification at any farm size. Otherwise, because the credit-constrained group in this case represents mid-sized farms, the overall effect on income distribution follows an "S" shaped relationship spreading income distribution among smaller farms and contracting income distribution among larger farms.

Long-Term Effects of Water Resource Policies on Intrasectoral Equity

Because resource policies can have serious short-run equity effects, they can also have important implications for long-term equity effects through the differential ability they give farmers to expand. That is, if a policy makes small farmers relatively better off than large farmers, the former may be able to compete more effectively in the land market for purposes of expansion and vice versa. This section considers heuristically the effects that different water resource policies can have on the farm size distribution and the resulting implications for future water resource policy considerations.

Consider, first, the case of raising effective water price in a partially irrigated region. Following the previous section, income distribution most likely contracts among the three behavioral regimes with smaller farm size. If these three regimes account for the entire farm size distribution, smaller farms will be able to compete better with large farms for expansion land; the long-term effect will be to concentrate farm size and resulting income distribution compared to the case with no change in water pricing. As small farms become relatively larger in this case, the policy can also have the effect of making irrigation attractive to some farms that are otherwise noninvestors because larger farm sizes allow fixed costs to be spread adequately; if this effect is large relative to the water price increase, the policy could lead to more irrigation investment or, at least, make future water conservation more expensive from a policy point of view.

Alternatively, if many farms are in the larger risk-diversifying regime, the spread in income distribution among large farm sizes may lead to a more skewed long-term farm size and income distribution. While this effect on equity may be undesirable, it may concentrate more land among farms that use a lower proportion of their productive resources under irrigation (e.g., L_2/L declines with farm size in the risk-diversifying regime while it is constant among specialized investors). Thus, the future policy cost of conserving water may be less in this case.

Consider next the effect of raising water price in an irrigated region with new water-conserving technology: Consider, first, the abundant credit case where the short-term effect is to contract both the absolute and relative income distributions. In this case, smaller noninvestors will be able to compete better for expansion, thus making investment in the water-saving technology more attractive. On the other hand, large risk diversifiers will be less able to compete for expansion land in a relative sense. Therefore, the long-term farm-size distribution could tend to concentrate in the specialized investor regime not only attaining intrasectoral equity but, also, the highest possible industry use of water-conserving technology.

Alternatively, suppose that credit constrains many farms from using as much water-conserving technology as they desire. The short-term spread in income distribution among these farms can cause a long-term spread in the farm size distribution. Depending on how farms are initially distributed among the behavioral regimes, this could cause more land to become concentrated among noninvestors than otherwise (e.g., if all land were held initially by farmers in the noninvesting and credit-constrained regimes), or land could become more concentrated among specialized investors (e.g., if all land were held initially by farmers in the credit-constrained or specialized investor regimes). Comparing the former case to the abundant-credit result suggests that offering government credit funding for investment in water-conserving technology may greatly improve the long-term effects of water-conservation policy.

Conclusions

This paper analyzes the intrasectoral equity effects of water resource policies related to agriculture. The results are derived in a framework exhibiting well-recognized features of the agricultural economy associated with credit market imperfections, risk aversion, availability of alternative technologies, various stochastic dependencies among alternative crops and technologies, and heterogeneity of farmers and farm size. A wide variety of results are obtained that may be appropriate for particular circumstances in specific regions. With respect to each policy, these circumstances may differ sufficiently so that the same policy may cause both the absolute and relative income distributions to spread in one set of circumstances while contracting in another. Nevertheless, the most likely equity effects of water-pricing policies aimed toward resource conservation appear, for the most part, to promote equity. Exceptions with respect to water policy occur only among large farms in partially irrigated regions or among mid-sized, credit-constrained farms in regions switching irrigated lands to water-saving technologies.

These results lead to important long-term considerations. In the case of encouraging investment in water-conserving technology in an irrigated region, these secondary effects are likely to be very desirable in promoting both equity and conservation—particularly when used in conjunction with credit policy. In the case of water-conservation policy in partially irrigated areas, the long-term equity effects are probably desirable; but the cost of future resource conservation becomes more expensive from a policy perspective.

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